Demonstration Abstract: OpenSky – A Large-scale ADS-B Sensor Network for Research

Matthias Schäfer*, Martin Strohmeier†, Vincent Lenders‡, Ivan Martinovic†, Matthias Wilhelm*

*TU Kaiserslautern, Germany
{schaefer, wilhelm}@cs.uni-kl.de

†University of Oxford, UK
{martin.strohmeier, ivan.martinovic}@cs.ox.ac.uk

‡armasuisse, Switzerland
vincent.lenders@armasuisse.ch

***Abstract*—The future of air traffic control (ATC) will heavily depend on the Automatic Dependent Surveillance - Broadcast (ADS-B) protocol as a crucial component. ADS-B marks a paradigm change in airspace monitoring as global ATC is switching from an independent, radar-based approach to dependent, satellite-supported surveillance. With ADS-B, aircraft broadcast their own position and other information in short periodic messages to other aircraft and control stations on the ground. As the protocol is becoming mandatory in most airspaces over the next years, it is important that its characteristics and challenges are thoroughly investigated. The large-scale ADS-B data required to do this has not been openly accessible until now, as specialized and expensive infrastructure was needed. We demonstrate OpenSky, a sensor network based on low-cost hardware connected over the Internet, which enables real-world experimental studies.**

OpenSky works with off-the-shelf sensors run by volunteers distributed over Central Europe. Currently comprising 11 sensors, the sensor network covers an area of 720,000 km². We capture more than 30 % of Europe's commercial air traffic, offering access to billions of ADS-B messages.

Keywords*—*ADS-B, Sensor Networks, OpenSky, NextGen, Air Traffic Control

I. Introduction

In order to meet future demands in increasingly congested airspaces, the world's aviation authorities are currently upgrading their air-traffic management systems. The Automatic Dependent Surveillance-Broadcast (ADS-B) protocol is at the core of the Next Generation Air Transportation (NextGen). In contrast to traditional radar surveillance technologies that measure the range and bearing of an aircraft from a ground-based antenna, ADS-B allows aircraft to determine their own position using a Global Navigation Satellite System (GNSS) and to broadcast it periodically over a radio frequency to ground stations or other aircraft. The ability to continuously broadcast position, altitude, heading, velocity, and other flight information lowers the necessity for more expensive and less accurate radar technologies. This improves the overall situational awareness of pilots and air traffic controllers significantly while reducing costs for air traffic surveillance.

Consequently, the Federal Aviation Administration (FAA) made ADS-B mandatory for all aircraft by 2020. Until then, many aspects of ADS-B need further clarification and evaluation to ensure a safe adoption. One important question is the validation of the ADS-B positional data which solely relies on GNSS data, making it independent of ground-based measurements. This means that ADS-B receivers do not have any physical means of verifying this information. Therefore, particular efforts should concentrate on validating ADS-B data against other technologies in order to detect inherent inaccuracies as well as malicious activity [1], [2].

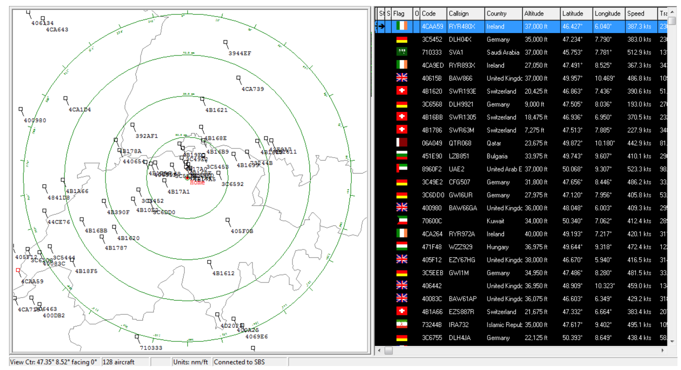

Figure 1. Live radar picture of the OpenSky airspace, showing 200 aircraft over a radius of 480 km (taken from Kinetic Avionic's BaseStation Software). The right-hand side shows a multitude of flight information such as callsign and country of origin as well as altitude and speed.

We believe that such validation is best achieved with an open research network since so far large-scale access to real-world data has been available only to a few selected industrial and governmental actors. To facilitate further research, we have developed OpenSky, an open sensor network for research, which collects and stores all ADS-B traffic captured by its sensors over a large geographical area.

II. Background on ADS-B

The ADS-B protocol introduces a new paradigm in airspace monitoring. In ADS-B, aircraft ascertain their own position using GNSS data and broadcast it along with other information in short periodic messages to other aircraft and stations on the ground. Data provided by ADS-B is employed for various different tasks. In en-route airspaces, aircraft and air traffic control will use ADS-B for improvement of the pilots' situational awareness, collision avoidance, and de-conflict planning. While ADS-B was primarily designed to manage traffic in the air, it is not intended solely for airborne usage. Another

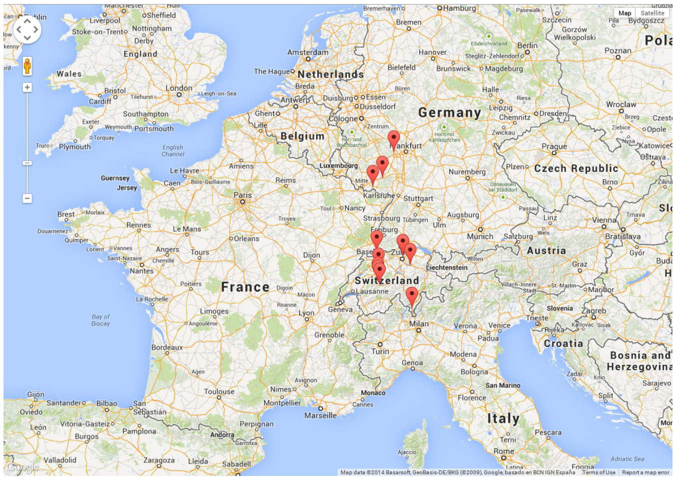

Figure 2. Locations of OpenSky's sensors. The sensors are placed at participants' homes, companies, and educational facilities.

Sensors	11 (SBS-3)
Received messages	>4,000,000,000
Total number of flights	>1,250,000
Unique aircraft	>13,200
Total size of MySQL DB	~800 GB
Covered area	~720,000 km²
Flights per day	7,000–7,500
Messages per day	>20,000,000
Total network throughput	$\sim 1 \pm 0.5$ MB/s

Table I. OPENSKY STATISTICS AS OF JANUARY 2014.

important function is to monitor traffic on the ground: vehicles may also be outfitted with ADS-B to make them part of the improved situational awareness and to detect conflicts when aircraft and vehicles are moving on the runway. It is crucial for air traffic control to monitor the runway for potential incursions and avoid dangerous approaches on parallel runways.

III. THE OPENSKY SENSOR NETWORK

OpenSky is a participatory network of ADS-B sensors distributed over Central Europe. The sensor hardware is provided to voluntary participants who deploy them at their homes or organizations. OpenSky currently comprises 11 sensor nodes (see Figure 2) and relies on low-cost off-the-shelf equipment, lowering the barrier of entry. We have been operating the network for two years, collecting billions of ADS-B messages for in-depth analysis (see Table I for current statistics). As currently deployed, the sensors of OpenSky cover 720,000 km² and capture over 30 % of all commercial flights in Europe. All contributing volunteers can access the collected data, which is also available on request.

OpenSky collects every ADS-B message received from aircraft in our sensing range and stores them in a database for further in-depth analysis. While there are existing services offering live visualization of air traffic on the Internet and providing substantial coverage of aggregated flight tracks and abstract information (e.g., Flightradar24), they offer no access to any of the historical raw data fundamental for independent research. The OpenSky sensor network should be seen as an effort to fill this gap.

Collected data

OpenSky collects and processes a plethora of data. Besides the primary message types identification, position and velocity of ADS-B-equipped aircraft, information on emergencies, priority, capability, navigation accuracy category, and operational modes are also collected.

Furthermore, we store metadata for each message, including timestamp of the reception, the receiving sensor's ID, the ADS-B checksum, and the raw message as a hex string. After an additional processing step, we also obtain aggregated information such as packet loss and signal quality.

IV. DEMO EXPERIENCE

- We give a live demonstration of OpenSky, including a hands-on experience of the hardware and showing our aggregated view of the Central European airspace as seen by our distributed sensors (Figure 1).
- We demonstrate the access to OpenSky's database that enables real-time data analysis and long-term analyses based on archived data.
- We provide live statistics of the ADS-B communication channel from OpenSky, characterizing real-world reception quality and loss patterns.
- We show examples of multilateration with ADS-B to demonstrate the feasibility of physical location validation with a low-cost infrastructure.
- We illustrate the network workload by means of bandwidth usage graphs and database utilization.

V. CONCLUSION

We demonstrate OpenSky, a low-cost participatory sensor network able to monitor air traffic for research purposes. Sensors deployed by volunteers capture ADS-B messages which are stored in a central database. Thus, OpenSky enables researchers to analyze unfiltered and non-abstracted data related to modern air traffic control. We furthermore provide insights on the challenges connected to the sensor network and its current capabilities. In addition, we demonstrate wide-area multilateration, to show practical applications based on OpenSky. In the future, we plan to continue extending both the scale and the scope of OpenSky.

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